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	First Inventor or Application Identifier	Irene T. Spitsberg
	Title	Aluminide Bond Coat for a Thermal etc
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3. <input checked="" type="checkbox"/> Abstract of the Disclosure 3. <input checked="" type="checkbox"/> Drawing(s) (35 U.S.C. 113) [Total Sheets 4]	ACCOMPANYING APPLICATION PARTS 7. <input checked="" type="checkbox"/> Assignment Papers (cover sheet & document(s)) 8. <input type="checkbox"/> 37 C.F.R. § 3.73(b) Statement (when there is an assignee) <input checked="" type="checkbox"/> Power of Attorney 9. <input type="checkbox"/> English Translation Document (if applicable) 10. <input checked="" type="checkbox"/> Information Disclosure Statement (IDS)/PTO-1449 [1] Copies of IDS Citations 11. <input type="checkbox"/> Preliminary Amendment 12. <input checked="" type="checkbox"/> Return Receipt Postcard (MPEP 503) (Should be specifically itemized) 13. <input type="checkbox"/> * Small Entity Statement(s) <input type="checkbox"/> Statement filed in prior application, Status still proper and desired (PTO/SB/09-12) 14. <input type="checkbox"/> Certified Copy of Priority Document(s) (if foreign priority is claimed) 15. <input type="checkbox"/> Other:
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ALUMINIDE BOND COAT FOR A THERMAL BARRIER
COATING SYSTEM AND METHOD THEREFOR

FIELD OF THE INVENTION

This invention relates to protective coating systems for components exposed to high temperatures, such as the hostile thermal environment of a gas turbine engine. More particularly, this invention is directed to a thermal barrier coating (TBC) system with an aluminide bond coat whose grain structure is modified to improve the spallation resistance of the TBC system.

BACKGROUND OF THE INVENTION

Higher operating temperatures for gas turbine engines are continuously sought in order to increase their efficiency. However, as operating temperatures increase, the high temperature durability of the components of the engine must correspondingly increase. Significant advances in high temperature capabilities have been achieved through the formulation of nickel and cobalt-base superalloys. Nonetheless, when used to form components of the turbine, combustor and augmentor sections of a gas turbine engine, such alloys alone are often susceptible to damage by oxidation and hot corrosion attack and may not retain adequate mechanical properties. For this reason, these components are often protected by an environmental and/or thermal-insulating coating, the latter of which is termed a thermal barrier coating (TBC) system. Ceramic materials and particularly yttria-stabilized zirconia (YSZ) are widely used as a thermal barrier coating (TBC), or topcoat, of TBC systems used on gas turbine engine components. TBC employed in the highest temperature regions of gas turbine engines is typically deposited by electron beam physical vapor deposition (EBPVD) techniques which yield a columnar

grain structure that is able to expand and contract without causing damaging stresses that lead to spallation.

To be effective, TBC systems must have low thermal conductivity, strongly adhere to the article, and remain adherent throughout many heating and cooling cycles. The latter requirement is particularly demanding due to the different coefficients of thermal expansion between ceramic topcoat materials and the superalloy substrates they protect. To promote adhesion and extend the service life of a TBC system, an oxidation-resistant bond coat is often employed. Bond coats are typically in the form of overlay coatings such as MCrAlX (where M is iron, cobalt and/or nickel, and X is yttrium or another rare earth element), or diffusion aluminide coatings. A notable example of a diffusion aluminide bond coat contains platinum aluminide (Ni(Pt)Al) intermetallic. When a bond coat is applied, a zone of chemical interaction occurs within the surface of the superalloy substrate beneath the coating. This zone is typically referred to as a diffusion zone (DZ), and results from the interdiffusion between the coating and substrate. The diffusion zone beneath an overlay bond coat is typically much thinner than the diffusion zone beneath a diffusion bond coat.

During the deposition of the ceramic TBC and subsequent exposures to high temperatures, such as during engine operation, bond coats of the type described above form a tightly adherent alumina (Al_2O_3) layer or scale that adheres the TBC to the bond coat. The service life of a TBC system is typically limited by a spallation event brought on by thermal fatigue. Spallation of TBC deposited on MCrAlX bond coats generally occurs within the TBC near the TBC-to-alumina interface, while TBC

deposited on diffusion aluminide bond coats typically spall at the alumina-to-bond coat interface or within the alumina layer itself. As a result, the alumina-to-bond coat interface is particularly critical for TBC systems that employ diffusion aluminide bond coats.

In view of the above, it can be appreciated that bond coats have a considerable effect on the spallation resistance of the TBC, and therefore TBC system life. Consequently, improvements in TBC life have been continuously sought, often through modifications to the chemistries of the bond coat. The effect of the surface finish of MCrAlY bond coats has also been investigated, as evidenced by U.S. Patent No. 4,414,249 to Ulion et al. The results of this investigation showed that the service life of a columnar TBC can be improved by polishing an MCrAlY bond coat before depositing the TBC. The benefit of improving the surface finish of an MCrAlY bond coat is believed to be that a smoother alumina layer grows, which in turn provides a more uniform surface upon which the columnar TBC is deposited. The initial portion of a columnar TBC consists of many small grains that appear to grow in a competitive fashion, by which more favorably oriented grains eventually dominate less favorably oriented grains. By polishing an MCrAlY bond coat, it is believed that Ulion et al. reduced the number of nucleated grains, thereby reducing growth competition and improving the quality of the TBC adjacent the alumina scale, i.e., in the very region that TBC spallation tends to occur on an MCrAlY bond coat. According to Ulion et al., an optional additional treatment is to dry glass bead peen an MCrAlY bond coat to densify any voids and improve the coating structure.

As noted above, TBC spallation initiates by a

different mechanism on diffusion aluminide bond coats, and primarily along the alumina-bond coat interface. Accordingly, the toughness of the alumina and the alumina-bond coat interface are most important to TBC deposited on a diffusion aluminide bond coat. From this perspective, polishing a diffusion aluminide bond coat would be expected to reduce TBC life, since sufficient surface roughness of the bond coat would be desired to promote adhesion of the alumina to the bond coat, and to inhibit crack propagation through the alumina and alumina-bond coat interface. As a result, conventional practice has been to grit blast the surface of a diffusion aluminide bond coat to increase its roughness to about 50 microinches (about 1.25 micrometers) Ra or more before depositing the TBC.

BRIEF SUMMARY OF THE INVENTION

The present invention generally provides an aluminide bond coat for a thermal barrier coating (TBC) system and a method for modifying the grain structure of the aluminide bond coat in order to improve the thermal fatigue life of the coating system. The bond coat can be a single-phase $[(\text{Ni}, \text{Pt})\text{Al}]$ or two-phase $[\text{PtAl}_2 + (\text{Ni}, \text{Pt})\text{Al}]$ diffusion aluminide, though it is believed that overlay aluminide bond coats can also benefit from the teachings of this invention. The invention is particularly directed to aluminide bond coats deposited by methods that produce a generally columnar grain structure, in which grains extend through the additive layer of the bond coat, i.e., from the diffusion zone beneath the additive layer to the bond coat surface, such that grain boundaries are exposed at the bond coat surface. Two widely-used methods that produce bond coats of this character are vapor phase aluminizing (VPA) and chemical vapor deposition (CVD).

According to the invention, an aluminide bond coat having generally columnar grains is recrystallized to eliminate the original grain boundaries throughout the bond coat or at least adjacent the bond coat surface. In so doing, more stable (preferably equiaxial) grains are created at the bond coat surface where the critical alumina-bond coat interface will exist following oxidation of the bond coat and/or deposition of TBC on the bond coat. In addition, the original surface texture of the bond coat is altered to be smoother where grain boundaries meet the bond coat surface, and the diffusion zone of the bond coat may be modified so that refractory phases originally present at the interface between the additive layer and diffusion zone of the bond cot are no longer at the grain boundaries.

The method of this invention generally entails depositing the columnar aluminide bond coat on a superalloy component, and then cold working and heat treating the bond coat so that at least the surface portion of the bond coat is recrystallized. According to one embodiment of the invention, the bond coat is peened with sufficient intensity to cause recrystallization of at least the surface of the bond coat when sufficiently heated, such as during an appropriate heat treatment or during deposition of the TBC. The effect of recrystallization is that new and preferably equiaxed grains form at the bond coat surface, replacing the original columnar grains. Also within the scope of the invention are triangular and columnar grains that form at the bond coat surface as a result of recrystallization.

According to this invention, the original columnar grains of an as-deposited aluminide bond coat were found to be prone to accelerated oxidation at their grain boundaries, with oxidation initiating in the grain

boundaries at the bond coat surface. Unexpectedly, the grain boundaries of recrystallized grains were shown to be much less prone to accelerated oxidation than the original grain boundaries. It is theorized that a lower oxidation rate at the grain boundaries eliminates a cause for the creation of initiation sites for localized creep and stress concentration at the bond coat surface, which are believed to cause the alumina layer to convolute and fracture. By eliminating or at least inhibiting the formation of sites where deformation of the alumina layer occurs, and thus where a fracture ultimately initiates and develops with thermal cycling, the spallation life of the TBC adhered by the bond coat is significantly increased. Another possibility is that the modified bond coat grain configuration exhibits more stable surface tension conditions, which slows a thermal grooving effect, that is, a tendency for the formation of valleys between adjacent grains.

Other objects and advantages of this invention will be better appreciated from the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view of a high pressure turbine blade.

Figure 2 is a cross-sectional representation of a TBC system on a surface region of the blade of Figure 1 along line 2--2.

Figures 3 through 5 show the progression of a spallation event of the TBC system of Figure 2.

Figure 6 is a cross-sectional representation of a TBC system with a diffusion aluminide bond coat exhibiting random recrystallization initiated at grain

boundary tips at the bond coat surface.

Figure 7 is a cross-sectional representation of a TBC system with an aluminide bond coat that has been fully recrystallized to yield equiaxial grains in accordance with a first embodiment of this invention.

Figure 8 is a cross-sectional representation of a TBC system with an aluminide bond coat whose surface region has been recrystallized to yield equiaxial grains limited to the surface region in accordance with a second embodiment of this invention.

Figure 9 is a cross-sectional representation of a TBC system with a single-phase aluminide bond coat that has been fully recrystallized with consequential grain growth in accordance with a third embodiment of this invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is generally applicable to components that operate within environments characterized by relatively high temperatures, and are therefore subjected to severe thermal stresses and thermal cycling. Notable examples of such components include the high and low pressure turbine nozzles and blades, shrouds, combustor liners and augmentor hardware of gas turbine engines. An example of a high pressure turbine blade 10 is shown in Figure 1. The blade 10 generally includes an airfoil 12 against which hot combustion gases are directed during operation of the gas turbine engine, and whose surface is therefore subjected to severe attack by oxidation, corrosion and erosion. The airfoil 12 is anchored to a turbine disk (not shown) with a dovetail 14 formed on a root section 16 of the blade 10. Cooling holes 18 are present in the airfoil 12

through which bleed air is forced to transfer heat from the blade 10. While the advantages of this invention will be described with reference to the high pressure turbine blade 10 shown in Figure 1, the teachings of this invention are generally applicable to any component on which a TBC system may be used to protect the component from its environment.

Represented in Figure 2 is a thermal barrier coating (TBC) system 20 of a type known in the art. As shown, the coating system 20 includes a bond coat 24 overlying a superalloy substrate 22, which is typically the base material of the blade 10. Suitable materials for the substrate 22 (and therefore the blade 10) include equiaxed, directionally-solidified and single-crystal nickel and cobalt-base superalloys. The bond coat 24 is shown as adhering a thermal-insulating ceramic layer 26, or TBC, to the substrate 22. As shown, the ceramic layer 26 has a strain-tolerant columnar grain structure achieved by depositing the ceramic layer 26 using physical vapor deposition techniques known in the art, particularly electron beam physical vapor deposition (EBPVD). A preferred material for the ceramic layer 26 is an yttria-stabilized zirconia (YSZ), a preferred composition being about 4 to about 8 weight percent yttria, though other ceramic materials could be used, such as yttria, nonstabilized zirconia, or zirconia stabilized by magnesia, ceria, scandia or other oxides. The ceramic layer 26 is deposited to a thickness that is sufficient to provide the required thermal protection for the underlying substrate 22 and blade 10, generally on the order of about 75 to about 300 micrometers.

The bond coat 24 is shown as being a diffusion aluminide of a type known in the art. The bond coat 24 is shown as being composed of an additive layer 28

overlying the substrate 22 and a diffusion zone 30 within the surface of the substrate 22. The diffusion zone (DZ) 30 contains various intermetallic and metastable phases that form during the coating reaction as a result of diffusional gradients and changes in elemental solubility in the local region of the substrate 22. The additive layer 28 is typically about 50 to 75 micrometers thick and contains the environmentally-resistant intermetallic phase MAl, where M is iron, nickel or cobalt, depending on the substrate material (mainly β (NiAl) if the substrate is Ni-base). The chemistry of the additive layer 28 is modified by the presence in the aluminum-containing composition of additional elements, such as chromium, silicon, platinum, rhodium, hafnium, yttrium and zirconium. For example, if platinum is deposited on the substrate 22 prior to aluminizing, the additive layer 28 consists of (Pt)NiAl-type intermetallic phases. The bond coat may be a single-phase [(Ni,Pt)Al] or two-phase [PtAl₂+(Ni,Pt)Al] diffusion aluminide.

The bond coat 24 is represented in Figure 2 as being in an as-deposited condition, i.e., without any additional treatment provided by the present invention. In the as-deposited condition, the additive layer 28 is characterized by grains 32 that extend from the diffusion zone 30 to the surface of the bond coat 24, so that the grains 32 are generally columnar. As also represented, the grains 32 have grain boundaries 34 that intersect the surface of the bond coat 24 at an angle approximately normal to the surface. Those portions of the grain boundaries 34 parallel to the bond coat surface and bordering the diffusion zone 30 are shown as being decorated (pinned) with refractory phases 46 formed during deposition of the bond coat 24 as a result of diffusion of refractory elements from the superalloy substrate 22. Finally, the surface of the bond coat 24

is characterized by surface irregularities, termed grain boundary ridges, that correspond to the locations of the grain boundaries 34. The type of microstructure represented in Figure 2 is typical of aluminide bond coats deposited by chemical vapor deposition (CVD) and vapor phase deposition, e.g., vapor phase aluminizing (VPA).

As depicted in Figure 3, the aluminum-rich bond coat 24 naturally develops an aluminum oxide (alumina) scale 36 when exposed to an oxidizing atmosphere, such as during high temperature exposures in air. As portrayed in Figures 3 and 4, the oxide scale 36 is convoluted, with valleys 38 present above a majority of the grain boundaries 34 at the bond coat surface. During engine service temperature exposure, the oxide scale 36 continues to grow beneath the permeable ceramic layer 26. Failure of the TBC system 20 during engine service exposure typically occurs by spallation of the ceramic layer 26 from cracks that initiate in the oxide scale 36 and then propagate into the interface between the bond coat 24 and oxide scale 36. Consequently, the strength of this interface, stresses within the interface plane, and changes with temperature exposure influence the life of the TBC system 20.

During an investigation leading to this invention, superalloy specimens were coated with a TBC system of the type shown in Figure 2. The superalloys were Rene' N5 with a nominal composition in weight percent of Ni-7.5Co-7.0Cr-6.5Ta-6.2Al-5.0W-3.0Re-1.5Mo-0.15Hf-0.05C-0.004B-0.01Y, and Rene' R142 with a nominal composition in weight percent of Ni-12Co-6.8Cr-6.35Ta-6.15Al-4.9W-2.8Re-1.5Mo-1.5Hf-0.12C-0.015B. The ceramic topcoat was YSZ deposited by EBPVD, while the bond coats were single and two-phase PtAl deposited by VPA or CVD.

The specimens were furnace cycle tested (FCT) at 2075°F (about 1135°C) at one-hour cycles to spallation, and then examined for appearance of the fracture mode that caused spallation. Observations made with these specimens suggested that spallation was brought on by a mechanism that involved convolution of the oxide scale 36, as portrayed in Figure 3. The convolutions were observed to typically initiate at the grain boundaries 34, and to further develop with oxide growth. Distinct valleys 38 formed as a result of the scale convolution eventually reached a critical depth/width ratio, at which point the scale 36 was bent at nearly a 90 degree angle (Figure 4). As shown in Figure 5, a crack 40 eventually formed in the scale 36 and typically propagated into the bond coat/oxide scale interface.

From this investigation, it was concluded that TBC spallation on a conventional diffusion aluminide bond coat occurred as a result of cracks developing at steep convolutions in the oxide scale, followed by multiple cracks propagating and linking together to cause an area of TBC to spall. It was also concluded that advanced convolutions which led to oxide cracking were associated with the bond coat grain boundaries. One possible reason for this observation was that accelerated oxidation of the grain boundaries occurred as a result of the grain boundaries often being decorated by tantalum-rich precipitates (e.g., the refractory phases 46 represented in Figure 2, which migrate during thermal cycling from those portions of the grain boundaries 34 at the diffusion zone 30 into those portions of the grain boundaries 34 near the bond coat surface).

Also observed during the investigation was that, as the convolution process developed at the bond coat grain boundaries, a random recrystallization process

initiated and developed at some of the grain boundary tips, as represented in Figure 6. The result was the formation of triangular-shaped grains 42 at the bond coat surface. Due to their small size, these "new" grains 42 quickly transformed into the gamma prime phase. It was speculated that recrystallization was caused by either internal growth stresses in the bond coat or surface tension at the grain boundary tips. Unexpectedly, the new grain boundaries 44 did not appear to be susceptible to the accelerated oxidation exhibited by the original grain boundaries 34, nor did convolution of the oxide scale appear to initiate at the new grain boundaries 44. Furthermore, the original grain boundaries 34 appeared to be different from the new grain boundaries 44, in that the original boundaries 34 were somewhat indistinct when viewed in an SEM backscatter image, whereas the new grain boundaries 44 were always straight and well defined. This suggested a difference in microstructures and properties. Another significant observation was that all original grain boundaries 34 were decorated with tantalum-rich phases. Surprisingly, when an original grain boundary 34 was replaced by a new grain boundary 44, no tantalum-rich phases 46 (or other refractory phases) were found in the new boundary 44. It was therefore concluded that certain properties or characteristics of the original and newly formed grain boundaries 34 and 44 were different, and that these differences affected the susceptibility of an aluminide bond coat to oxidation and development of the oxide convolution process.

Based on the above, it was concluded that PtAl bond coats having columnar grain structures as a result of the deposition process are not favorable for the thermal fatigue properties of a TBC. It was proposed that a different microstructure could improve TBC life.

In response to the above, a process for intentionally recrystallizing at least the surface of an aluminide bond coat was investigated for the purpose of evaluating the effect on TBC life. The investigation was directed to achieving and evaluating two effects: modification of the bond coat microstructure through controlled recrystallization to alter grain boundary structure, strength and chemistry, and modification of the bond coat surface stresses localized at grain boundaries through altering the surface grain morphology. It was postulated that the latter could be beneficial to eliminate high stress concentrations where grain boundaries create irregularities in the bond coat surface, as seen in Figure 2.

TRIAL #1

In a first trial, a group of specimens were coated with TBC systems that included VPA two-phase PtAl diffusion bond coats, and then evaluated by furnace cycle testing (FCT) at about 2075°F (about 1135°C) with one-hour cycles. All of the specimens underwent conventional grit blasting (80 alumina grit at 60 psi), while a limited number of the specimens were subjected to various intensity levels of zirconia bead peening, including intensity levels of about 8A (100% coverage), which is above that achievable with the dry glass bead peening (up to 6A) taught by U.S. Patent No. 4,414,249 to Ulion et al. Some of the peened specimens achieved a FCT life that was about 1.5 to 2 times greater than that of the baseline specimens (grit blasted only). A detailed examination of the best peened specimens revealed that the TBC spallation mode in these specimens was different from the typical mode shown in Figures 2 through 5. Specifically, TBC spallation occurred as a result of a relative smooth oxide delamination from the bond coat,

with grain boundary convolutions rarely being observed.

Some of the shot peened specimens exhibited overall or at least surface recrystallization of the PtAl bond coat as depicted in Figures 7 and 8, respectively, in which reference numbers are used consistent with the same features represented in Figures 2 through 5. In these fully and partially recrystallized specimens, the surfaces of the bond coats 24 at failure were smoother than that of the baseline unpeened bond coats (i.e., bond coat 24 in Figure 2), and the recrystallized grains 48 were substantially equiaxed instead of the columnar shape of the original grains (i.e., grains 32 in Figure 2). Yet other peened specimens developed triangular-shaped grains in certain regions of their bond coat surfaces, similar to the grains 42 shown in Figure 6. These specimens were concluded to have been peened at less than optimal intensities. The recrystallized bond coats were observed during examination to be single-phase as a result of the second phase having dissolved during recrystallization.

Finally, other peened specimens from the same investigation did not yield any higher level of FCT life as compared to the baseline specimens. These specimens did not exhibit bond coat recrystallization or consistent formation of triangular grains at the coating surface. Furthermore, the spallation mechanism for these specimens did not appear to be different from the typical spallation mode on the baseline samples.

From the above, it was observed that an aluminide bond coat that had undergone recrystallization to yield equiaxial grains could result in significantly improved spallation resistance (about 1.5 to 2 times improved FCT life) as compared to the aluminide bond coats that had not undergone a similar recrystallization.

Because recrystallization is dependent on peening intensity (cold working), it was concluded that a sufficient peening intensity was critical to achieving improved spallation resistance by way of the recrystallization observed for the best specimens from this trial. Consequently, peening an aluminide bond coat for the limited purpose of improving surface finish (e.g., Ulion et al.) would not result in the recrystallization effect sought by the present invention.

TRIAL #2

In a second trial, the surfaces of six Ni-based superalloy specimens coated by VPA with single-phase PtAl bond coats were shot peened with zirconia or stainless steel shot with an intensity of about 10A and a coverage of about 100%, followed by heat treatment at about 2050°F (about 1120°C) for one hour. The heat treatment caused recrystallization throughout the additive layers of the bond coats, though with grain growth that yielded the microstructure represented in Figure 9. It was concluded that, because these bond coats were single-phase PtAl and therefore lacked the second phase of the previously tested specimens, the fine equiaxed grain microstructure resulting from the two-phase structures (Figures 7 and 8) was not obtained. Instead, the new grains that developed extended into the original diffusion zone, thereby displacing the refractory phases from the new grain boundaries. As a result of recrystallization, the surfaces of the bond coats were "reformed," causing all original surface features to disappear. The reformed bond coat surfaces were much flatter than the as-deposited bond coat surfaces, which had grain boundary ridges characteristic of the deposition process (Figure 2). However, fine steps of about one to two micrometers were observed to form between adjacent recrystallized

grains 50.

The specimens were then coated with 7%YSZ deposited by EBPVD and tested by FCT at about 2125°F (about 1160°C) with one-hour cycles. The TBC life of the recrystallized specimens was about 300 to 320 cycles, while historically specimens of this type spall after an average of about 230 cycles. From these results, it was concluded that the peening and heat treatment parameters are sensitive to the coating type, i.e., single-phase versus two-phase aluminide bond coats. Specifically, the single-phase aluminide bond coats did not develop the equiaxial grains characteristic of two-phase aluminide bond coats and, apparently as a result, did not exhibit as great an increase in spallation resistance.

In view of the above, the present invention provides for the recrystallization aluminide bond coats to yield a grain structure capable of improving the service life of a TBC adhered to the bond coat. Recrystallization can be induced by a surface mechanical treatment that introduces cold working into the bond coat, so that a surface region or the entire bond coat undergoes recrystallization when sufficiently heated to drive the recrystallization process. Based on test results, shot peening with full surface coverage and an intensity of at least 6A is believed to be necessary. More particularly, a shot peening intensity of about 6A to 10A is believed optimal for two-phase aluminide bond coats to yield an equiaxial microstructure (Figures 7 and 8) during subsequent heat cycles. The maximum intensity of this range is established by that which the bond coat can withstand without incurring brittle fracture. In contrast, a higher shot peening intensity of about 8A to 12A is believed necessary for single-phase aluminide bond coats to yield the microstructures represented in Figures

7 through 9. The maximum intensity for this range is limited to avoid damage to the component surface and alloy properties beneath the bond coat.

The equiaxial microstructure (Figures 7 and 8) achieved with the two-phase aluminide bond coats was only occasionally observed with the single-phase aluminide bond coats after recrystallization, and it appears as a consequence that a lesser degree of improvement in spallation resistance was achieved for the single-phase bond coats. However, it is possible that an equiaxial microstructure could be more consistently achieved with a single-phase aluminide bond coat if processed with different cold working and heat treatment parameters.

While shot peening is the preferred cold working method as it can be well controlled and characterized in terms of stresses distribution, it is foreseeable that other cold working methods could be used. Furthermore, while recrystallization was caused to occur throughout the tested specimens, it is believed that the recrystallization of grains at only the aluminide bond coat surface could yield desirable results, since the spallation mechanism in an aluminide bond coat initiates and propagates from the alumina-bond coat interface.

In addition, while the recrystallization process is preferably initiated with a specific heat treatment for this purpose, recrystallization can also be accomplished during deposition of the TBC in some cases. A preferred heat treatment is believed to be a temperature of about 2000°F to about 2100°F (about 1090°C to about 1150°C) for a duration of about 0.5 to three hours. A preferred final grain size for the equiaxed grains of the recrystallized bond coat is not less than five micrometers in order to discourage aluminum loss

While the invention has been described in terms
5 of a preferred embodiment, it is apparent that other
forms could be adopted by one skilled in the art.
Therefore, the scope of the invention is to be limited
only by the following claims.

CLAIMS:

1. A method of improving the thermal fatigue life of a thermal barrier coating by modifying the grain structure of an aluminide bond coat that adheres the thermal barrier coating to a surface of a superalloy component, the method comprising the steps of:

depositing the aluminide bond coat on the component so as to be characterized by substantially columnar grains that extend substantially through that portion of the bond coat overlying the surface of the component, the grains having grain boundaries exposed at the surface of the aluminide bond coat; and then

recrystallizing at least a surface region of the aluminide bond coat during or prior to depositing the thermal barrier coating on the surface of the aluminide bond coat, wherein new grains form at the surface of the aluminide bond coat.

2. A method according to claim 1, wherein recrystallization is induced by peening the aluminide bond coat at an intensity of at least 6A prior to heating the aluminide bond coat.

3. A method according to claim 1, wherein the aluminide bond coat is heated to a temperature of about 1090°C to about 1120°C.

4. A method according to claim 1, wherein the new grains have a grain size of not smaller than five micrometers after recrystallization.

5. A method according to claim 1, wherein the new grains are substantially equiaxed.

6. A method according to claim 5, wherein the

aluminide bond coat is a single-phase or two-phase aluminide.

7. A method according to claim 1, wherein precipitates are substantially absent from the grain boundaries.

8. A method according to claim 7, wherein the aluminide bond coat is a single-phase aluminide.

9. A method according to claim 1, wherein the aluminide bond coat is a diffusion aluminide bond coat.

10. A method according to claim 1, wherein the aluminide bond coat is an overlay aluminide bond coat.

11. A method of improving the thermal fatigue life of a thermal barrier coating by modifying the grain structure of an aluminide bond coat that adheres the thermal barrier coating to a surface of a superalloy component, the method comprising the steps of:

depositing the aluminide bond coat on the component by vapor phase aluminizing or by chemical vapor deposition, the aluminide bond coat comprising an additive layer on the surface of the component and a diffusion zone in a surface region of the component, the additive layer being characterized by columnar grains that extend from the diffusion zone to the surface of the aluminide bond coat, the grains having grain boundaries exposed at the surface of the aluminide bond coat;

peening the surface of the aluminide bond coat at an intensity of at least 6A; and then

heat treating the aluminide bond coat before or while depositing the thermal barrier coating on the surface of the aluminide bond coat so as to recrystallize at least a surface region of the aluminide bond coat,

wherein new grains form within the additive layer at the surface of the aluminide bond coat.

12. A method according to claim 11, wherein the aluminide bond coat is heat treated at a temperature of about 1090°C to about 1120°C.

13. A method according to claim 11, wherein the new grains have a grain size of not smaller than five micrometers after the thermal barrier coating has been deposited.

14. A method according to claim 11, wherein the new grains are substantially equiaxed.

15. A method according to claim 14, wherein the aluminide bond coat is a single-phase or two-phase aluminide.

16. A method according to claim 11, wherein precipitates are substantially absent from the grain boundaries.

17. A method according to claim 16, wherein the aluminide bond coat is a single-phase aluminide.

18. A method according to claim 11, wherein the aluminide bond coat is a diffusion aluminide bond coat.

19. A method according to claim 11, wherein the aluminide bond coat is an overlay aluminide bond coat.

20. A method of improving the thermal fatigue life of a thermal barrier coating by modifying the grain

structure of a diffusion aluminide bond coat that adheres the thermal barrier coating to a surface of a superalloy component, the method comprising the steps of:

depositing the diffusion aluminide bond coat on the component by vapor phase aluminizing or by chemical vapor deposition, the diffusion aluminide bond coat comprising an additive layer on the surface of the component and a diffusion zone in a surface region of the component, the additive layer being characterized by columnar grains that extend from the diffusion zone to the surface of the diffusion aluminide bond coat, the grains having grain boundaries exposed at the surface of the diffusion aluminide bond coat;

peening the diffusion aluminide coat bond coat at an intensity of 6A to 12A;

heat treating the diffusion aluminide coating at a temperature and for a duration sufficient to cause recrystallization of the entire additive layer of the diffusion aluminide bond coat, wherein equiaxial grains form within the additive layer; and then

depositing the thermal barrier coating on the diffusion aluminide bond coat;

wherein the new grains have a grain size of about fifteen to thirty micrometers.

21. An aluminide bond coat of a thermal barrier coating system on a surface of a superalloy component, the bond coat comprising an additive layer overlying the surface of the component and a diffusion zone in a surface region of the component, the additive layer having triangular grains at a surface of the bond coat and having substantially columnar grains in a portion thereof adjacent the surface region of the component.

22. An aluminide bond coat according to claim

21, wherein refractory precipitates are substantially absent from grain boundaries of the triangular grains.

23. An aluminide bond coat according to claim 21, wherein the bond coat is a single-phase aluminide.

24. An aluminide bond coat according to claim 21, wherein the bond coat is a two-phase aluminide.

25. An aluminide bond coat according to claim 21, wherein the bond coat is a diffusion aluminide bond coat.

26. An aluminide bond coat according to claim 21, wherein the bond coat is an overlay aluminide bond coat.

27. An aluminide bond coat according to claim 21, wherein the thermal barrier coating system comprises a ceramic layer overlying the bond coat, the ceramic layer having a columnar grain structure.

28. An aluminide bond coat of a thermal barrier coating system on a surface of a superalloy component, the bond coat comprising an additive layer overlying the surface of the component and a diffusion zone in a surface region of the component, the additive layer having equiaxial grains at at least a surface of the bond coat and having substantially columnar grains in a portion thereof adjacent the surface region of the component.

29. An aluminide bond coat according to claim 28, wherein the equiaxial grains have a grain size of not smaller than five micrometers.

30. An aluminide bond coat according to claim 28, wherein the bond coat is a single-phase or two-phase aluminide.

5 31. An aluminide bond coat according to claim 28, wherein refractory precipitates are substantially absent from the grain boundaries of the equiaxial grains.

10 32. An aluminide bond coat according to claim 28, wherein the bond coat is a diffusion aluminide bond coat.

15 33. An aluminide bond coat according to claim 28, wherein the bond coat is an overlay aluminide bond coat.

20 34. An aluminide bond coat according to claim 28, wherein the thermal barrier coating system comprises a ceramic layer overlying the bond coat, the ceramic layer having a columnar grain structure.

25 35. An aluminide bond coat of a thermal barrier coating system on a surface of a superalloy component, the bond coat comprising an additive layer overlying the surface of the component and a diffusion zone in a surface region of the component, the additive layer having grains that extend from a surface of the bond coat into the surface region of the component, the grains having grain boundaries that are substantially
30 free of refractory phases.

36. An aluminide bond coat according to claim 35, wherein the bond coat is a single-phase aluminide.

35 37. An aluminide bond coat according to claim 35, wherein the bond coat is a diffusion aluminide bond

coat.

38. An aluminide bond coat according to claim
35, wherein the bond coat is an overlay aluminide bond
coat.

39. An aluminide bond coat according to claim
35, wherein the thermal barrier coating system comprises
a ceramic layer overlying the bond coat, the ceramic
layer having a columnar grain structure.

ABSTRACT OF THE DISCLOSURE

An aluminide bond coat for a thermal barrier coating (TBC) system and method for modifying the grain structure of the aluminide bond coat in order to improve the thermal fatigue life of the coating system. As deposited, the aluminide bond coat has columnar grains that extend from a diffusion zone beneath the bond coat to the bond coat surface, such that grain boundaries are exposed at the surface of the bond coat. The surface of the bond coat is then peened or otherwise cold worked with a sufficient intensity to cause recrystallization of at least the surface of the bond coat when sufficiently heated, such as during a subsequent heat treatment or during deposition of a ceramic topcoat. The effect of recrystallization is that new grains form at the bond coat surface, replacing the original columnar grains.

FIG. 1

A cross-sectional view of a multi-layered material assembly. At the top, a series of vertical, pointed structures (26) are shown. Below these is a layer (28) containing a series of small circles (46). A dashed line (34) is positioned below the circles. The bottom layer (22) is hatched. A bracket (20) groups the top two layers, and another bracket (24) groups the middle two layers.

A cross-sectional view of a multi-layered material. The top layer, labeled 26, consists of a series of vertical, pointed structures. Below this is a layer labeled 36. The interface between 36 and the layer below is wavy. A row of small circles, labeled 28, is located within the layer below the wavy interface. A dashed horizontal line, labeled 30, passes through the circles. Below the dashed line is a layer labeled 32. A bracket on the right side, labeled 20, encompasses the wavy interface, the layer with circles, and the dashed line. A bracket on the left side, labeled 24, encompasses the wavy interface and the layer with circles. A circular inset, labeled 38, shows a magnified view of the wavy interface. Other labels include 4, 22, 34, and 46.

FIG. 5 (PRIOR ART)

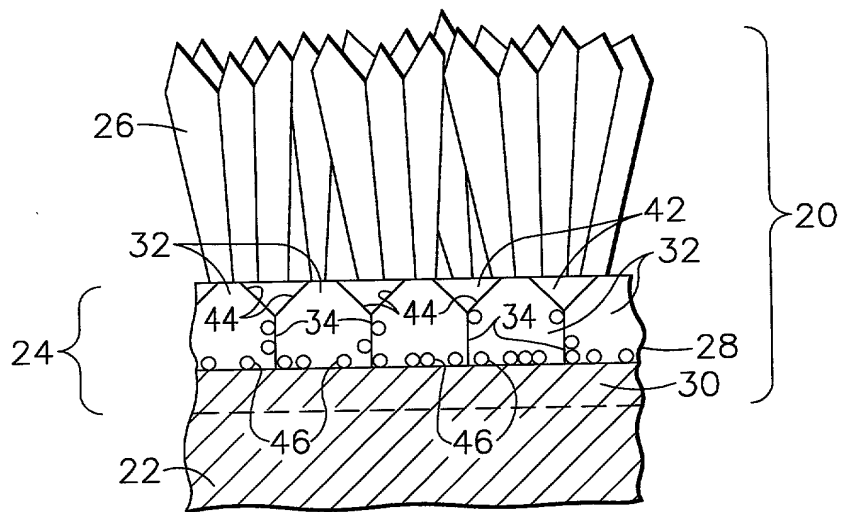


FIG. 6

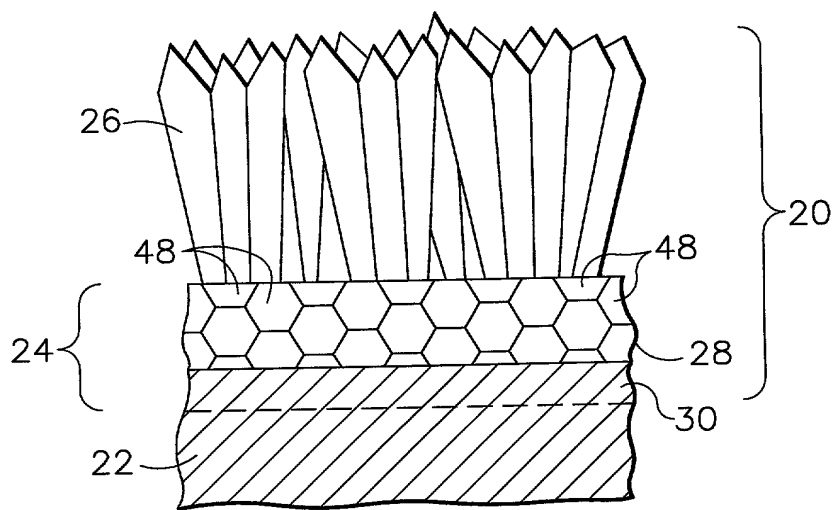


FIG. 7

A cross-sectional view of a multi-layered material. The top layer, labeled 20, consists of a series of vertical, elongated, pointed structures 26. Below these is a layer 24 containing a hexagonal pattern 48. The bottom layer, labeled 22, is hatched and contains a series of vertical lines 30. A bracket on the right side groups the top layer 20 and the bottom layer 22. A label 28 points to the interface between the hexagonal pattern 48 and the hatched layer 22. A label 48 points to the hexagonal pattern 48.

A cross-sectional view of a multi-layered material. The top surface is textured with a series of sharp, upward-pointing peaks. Below this surface is a layer containing a series of small, circular features. The bottom of the structure is a solid, hatched layer. Various components are labeled with reference numerals: 22, 24, 26, 28, 30, 46, 50, and 52. A bracket on the right side groups the top two layers together, labeled 20.

FIG. 9

**DECLARATION AND POWER OF ATTORNEY
FOR PATENT APPLICATION**

Docket Number
13DV13004

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

ALUMINIDE BOND COAT FOR A THERMAL BARRIER COATING SYSTEM AND METHOD THEREFOR

the specification of which

☒ is attached hereto
OR

☐ was filed on _____ as United States Application Number or PCT International Application Number _____
and was amended on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37 Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code §119 (a)-(d) or §365 (b) of any foreign application(s) for patent or inventor's certificate, or §365 (a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

PRIOR FOREIGN APPLICATION(s)

Priority Claimed

☐ Yes ☐ No

☐ Yes ☐ No

_____ (Number)	_____ (Country)	_____ (Day/Month/Year Filed)
_____ (Number)	_____ (Country)	_____ (Day/Month/Year Filed)

☐ Additional foreign application numbers are listed on a supplemental priority data sheet attached hereto.

I hereby claim the benefit under Title 35, United States Code §119 (e) of any United States provisional application(s) listed below.

☐ Additional provisional application numbers are listed on a supplemental priority data sheet attached hereto.

_____ (Application Number)	_____ (Filing Date)
-------------------------------	------------------------

I hereby claim the benefit under Title 35, United States Code §120 of any United States Application(s), or §365 (c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

_____ (Application Number)	_____ (Filing Date)	_____ (Status - patented, pending, abandoned)
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_____ (Application Number)	_____ (Filing Date)	_____ (Status - patented, pending, abandoned)
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I hereby appoint the registered practitioners associated with Customer Number 006111 to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Middle Name

Last Name

Signature: _____

Date

Residence: _____

City and State

Citizenship: _____

Post Office Address: _____